



Seismic Facies Interpretation of ‘X’ and ‘Y’ Fields, Central Depobelt, Niger Delta, Nigeria

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Abstract

This paper presents the result of a study carried out in ‘X’ and ‘Y’ fields of the Central Depobelt of the Niger Delta. This study observed successions of the sediments being deposited progressively basinwards and is overlain by thick marine shales and clay deposits. These thick, sand rich wedges are separated from each other by thinner up-dip extending sediments of fossiliferous marine shales. The interpretation of the extracted seismic horizons of the five In-lines and one X-line showed more conspicuous and varied seismic pattern which has a smooth texture; high-amplitude; with a discontinuous rugged texture; whereas the chaotic seismic pattern was observed to possess a low coherence attribute. On the other hand, the low amplitude and variable frequency has a less predictable texture than a high-amplitude, continuous, coherent reflection pattern. Seismic facies packages have been delineated in this study based on seismic attributes such as reflection configuration, uniform amplitude reflections, geometry, frequency and continuity. The sand geometries and reflection patterns are either sheets or sheet-drape shapes in nature. These inferred sand-prone depositional units are based on their reflection amplitude and continuity patterns and are described as parallel to sub-parallel. Hummocky and chaotic reflection packages which depict debris flow, slump structures were also interpreted within the seismic sections. It was observed in seismic sections that the Maximum Flooding Surfaces marked on the wells commonly appear as thick amplitude event that form the upper bounding surfaces of the sandy, bright-amplitude intervals. In all stage boundaries, it coincides with flooding surfaces which occur at the tops of major upward-fining successions in the shelf deposits and ranges conspicuously between 1.9 – 3.0secs within the sections. The amplitude anomalies are low and the reflection geometry are described as being contorted and discordant, therefore, interpretation of this facies unit is associated with high energy environments which depicts Foreshore – Upper shoreface depositional setting. Faults encountered in these wells include normal growth, crestal (synthetic and antithetic) and minor counter - regional faults respectively. The normal faults are dipping in a north – south direction, crestal faults (including the synthetic and antithetic) are dipping in the (north – west and north – east) landward direction while the counter regional fault (back - to - back) are dipping in a west – south direction respectively.

Keywords: Seismic stratigraphy, Seismic pattern, Reflection termination/configuration, Central Depobelt and Niger Delta.

Introduction

This study characterizes the seismic stratigraphic play within fields 'X' and 'Y' of the Central Depobelt in the Niger Delta. Analysis from the seismic sections showed that the Maximum Flooding Surfaces within the wells under study commonly appear as thick amplitude events that form the upper bounding surfaces of the sandy, bright-amplitude intervals. Isochronous shales, along with stratal termination patterns recognized from seismic analysis provided additional confidence to correlation across faults. The seismic sections in this study were calibrated in depths to ensure consistency with well data for ease of stratigraphic interpretation. Key stratigraphic surfaces were then posted on the seismic sections and well- to - seismic match was also attempted with the log imposition. The Maximum Flooding Surfaces (MFS) were mapped as seismic horizons and carried across the entire sections. The two-way- time equivalent employed in this study was correspondingly used for the calibration of the key candidate surfaces, namely; the Maximum Flooding Surfaces (MFSs) and Sequence Boundaries (SBs). These Maximum Flooding Surfaces have coincided in most cases with very strong continuous reflectors and they were strictly observed as downlapping events. The bulk geometries and reflection patterns in the studied interval suggest that most of the depositional facies were deposited as distributary channels and bar complexes found within the Foreshore – Upper shoreface paleoenvironmental setting. These are inferred to be sand-rich depositional units based on (1) moderate to high reflection amplitude and continuity (2) onlapping, compensating, and locally erosional internal reflection geometries and (3)

distributary channel observed patterns. Acoustically chaotic, hummocky or transparent seismic reflection packages have been interpreted as debris-flow deposits, slumps or mass-transport deposits within the seismic volume. However, in this study area beneath the suggested chaotic reflections, diapiric movement of underlying mobile shale with complicated reflector geometry was encountered. Seismic stratigraphic analysis of the five In-lines and one X-line seismic lines was carried out. The purpose of this was to build a sequence stratigraphic facies model of the 'X' and 'Y' fields.

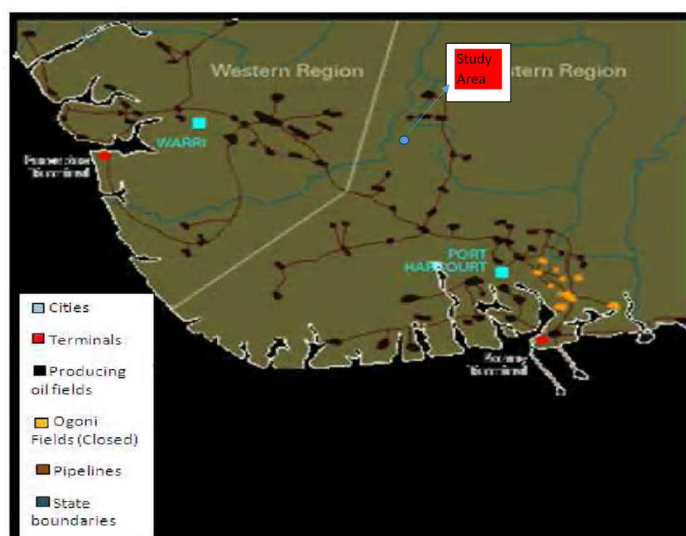


Fig. 1. Location map of the Niger Delta showing 'MR'- Well (Modified from Imasuen et al., 2011).

Fields Geologic Setting and General Geology of the Niger Delta

Geographically, the Niger Delta and the study area are located between longitude 5° and 8° E and latitude 3° and 6° N respectively (Fig. 1 and 2). The Niger Delta occupies the Gulf of Guinea continental margin in equatorial West Africa. This basin occupies a total area of about $7,500\text{km}^2$ in the Gulf of Guinea with a sediment thickness up to $12,000\text{m}$

(Bustin, 1988; Burke, 1972). Reijers et al. (1997) documented that the sedimentary basin of the Niger Delta encompasses a much larger extent region than the modern delta constructed by the Niger – Benue drainage system. This includes the Cross River delta and further extends eastwards into the continental margins of neighboring Cameroon and Equatorial Guinea sub-environments. The sedimentary wedge of the Niger Delta contains a major submarine part which forms part of the complex continental margin intruding into the Gulf of Guinea (Reijers, 1996). The recent sedimentary environments of the Niger Delta serve as a classic model for high energy, wave-dominated, constructional arcuate-lobate tropical deltas (Reijers et al. 1997). The Niger Delta is built in a series of depocenters extending over the continental edge and onto the oceanic basement. It consists of predominantly regressive sequence ranging in age from Eocene to Recent (Khani and Back, 2012).

is undergoing deformation by gravity tectonism caused by rapid stepwise seaward sediment progradation over a strong thickness of shale deposits (Bhattacharya and Davies, 2001 and Evamy et al., 1978). The progradation of the deltaic sequence has been controlled by syn-sedimentary faults and the interplay between subsidence and sediment supply. Each depobelt contains one or more paleontologically distinct transgressive shale horizon. These transgressive shales represent interruptions in the overall regressive sequence that is probably related to sea-level rises. The fundamental trend, however, consists of a stepwise building up of offlap cycles within each depobelt that gradually progrades southward. The result is a gradual increase in sand percentage up-section. According to Petters, (1982), Short and Stuable, (1967), many other workers and multinational companies that carried out work in this area have recorded that the major lithostratigraphic sequences or units found within the Niger Delta formation include, the Benin Formation, Agbada and Akata Formations respectively. These formations showed intercalations of sand, shale, silt and/or sandstone facies equivalents which represent the delta plain, delta front and prodelta environments.

1. Benin Formation: Directly overlying the Agbada Formation in the Niger Delta is the upper continental deltaic plain called the Benin Formation. It is mainly made of fresh water, fluvial sands and gravels with occasional coal seams, lignites and shale beds of about 2500m (8,250ft) thick. Evamy et al. (1978) and Stacher (1995) reported that this formation has 9:1 sand/shale ratio interbeds (Table 1). The sand varies in grain size from fine to very coarse and sometimes pebbly in places. Sorting is more or less poor and grains are sub-angular to well rounded, yellowish brown to clean quartz grains, which are occasionally ferruginized (hematite stains). Many companies exploring for oil in the Niger Delta had arbitrarily

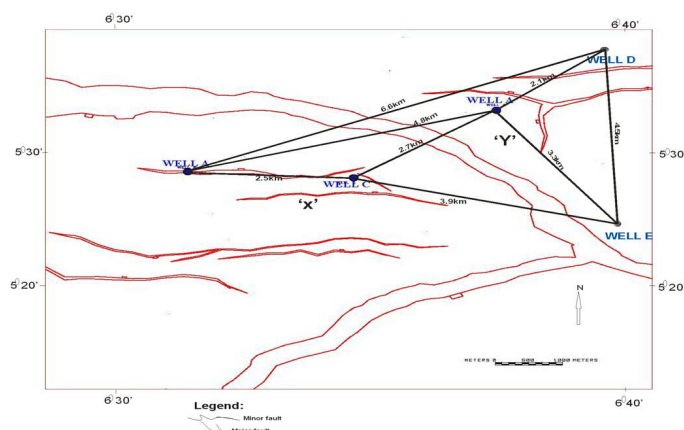


Fig. 2. Location of wells and their distances within the two fields in the Central Niger Delta.

This progressively out-building of the Niger Delta is illustrated by the seaward shift in the inferred positions of the coastline from Eocene to the present, this shows that the landward position of the coastline is anomalous and is due to the post-glacial rise in sea level thus the continental Benin Formation extends offshore. The continental margin off the Niger Delta

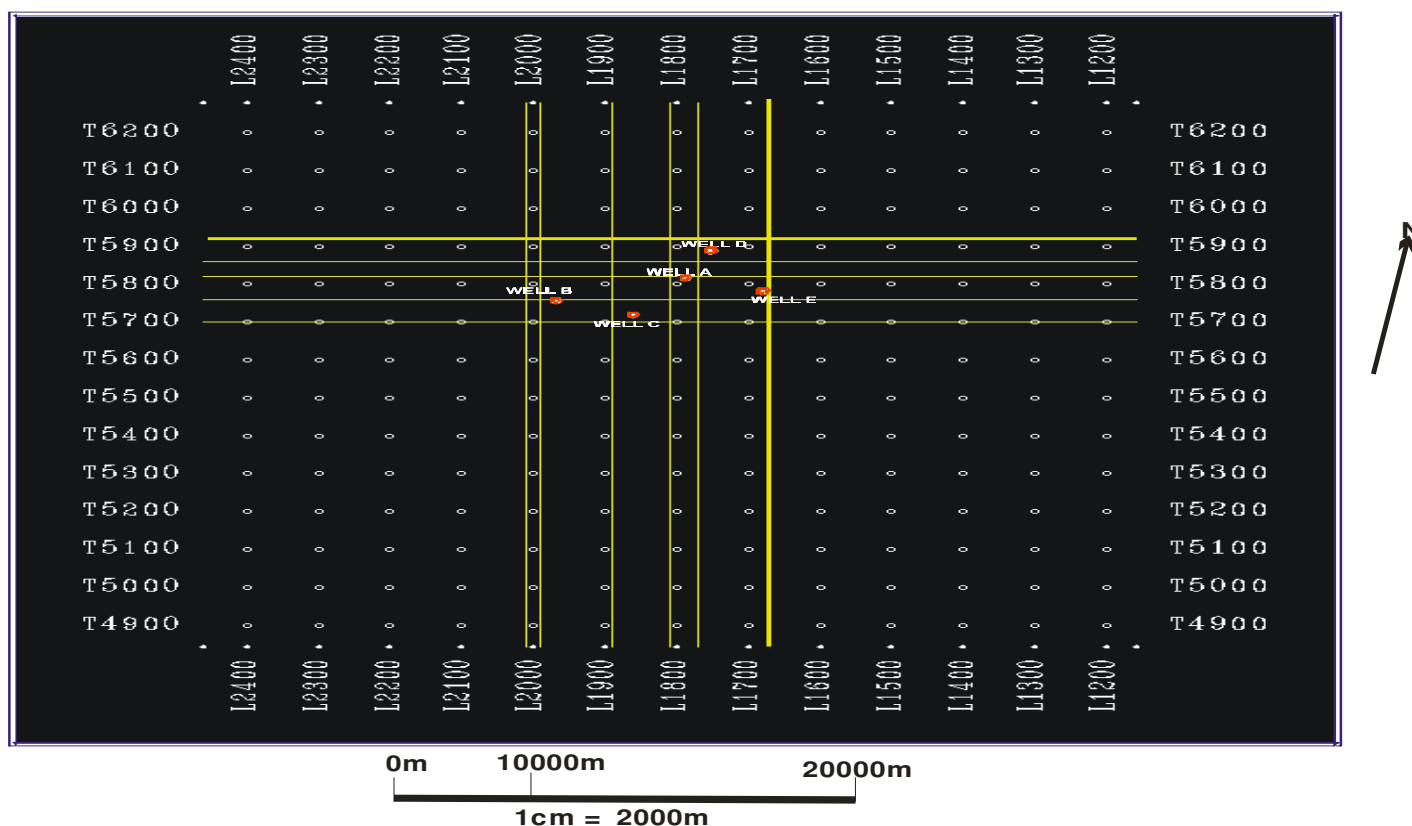


Fig. 3. Base map showing the wells location on the T-L locations.

defined the base of Benin Formation by the deepest fresh water bearing sandstone that exhibits relative high resistivity. However, the base of this formation is defined by the first marine deposit (Short and Stuabie, 1967) and this includes massive coarse-grained sands from the non-marine (Coastal deltaic) or continental environment that make up this formation. This formation is commonly cross-bedded and also seldomly faulted. Benin Formation is dated Oligocene to Recent in age.

2. Agbada Formation: This formation is underlying by the continental sand sequence of the Benin Formation. It is characterized by paralic to marine deposits mainly composed of sandstones and shales organized into coarsening (shoaling) upward offlap cycles. The Agbada Formation is diachronous with a thickness of about 4,500m (14,850ft). This formation ranges in age from Upper Miocene in the north to Pliocene – Pleistocene in the south. Oyifo, (1983)

and Avbovbo, (1978) documented that the sands of the Agbada Formation are the main reservoirs in the Niger Delta with shale providing lateral and vertical seal. The sediments vary in from fine to very coarse grained, light to reddish brown (ferruginized), poorly to well sorted and unconsolidated to fairly consolidated. The shales on the other hand are dark to light grey, hard to moderately hard and sub-fissile to fissile with occasional shell fragments occurrences. However, Ekweozor and Okoye, (1980) reported that the shale of the lower Agbada Formation has the potentials for hydrocarbon generation.

3. Akata Formation: The basal sedimentary unit of the Niger Delta is the Akata Formation which includes at least 6,500m (21,400ft) of marine clays with silty and sandy interbeds (Whiteman, 1982). This formation is overlain by the paralic sand/shale sequence of the Agbada Formation representing 3:2 ratio of sand to shale (Evamy et. al., 1978). The

Table 1. Lithofacies and Ratio scheme for the Niger Delta formation (After Stacher, 1995).

FORMATION	LITHOLOGY		
	Sand (%)	Shale (%)	Ratio
Benin	90	10	9 : 1
Agbada	60	40	3 : 2
Akata	20	80	1 : 4

paralic sand/shale succession in this formation is attributed to the differential subsidence of these sediment and shifts of the delta depositional axes which cause local transgressions and regressions. In the same vein, Beka and Oti, (1995) reported that this formation has a clastic sediment thickness of about 6,000m (19,800ft). This formation is composed of shales, generally dark to light grey in colour and sandy to silty in places (Asseez, 1976). Within this formation are traces of plant remains, minor pyrites, glauconites, faecal pellets and mica minerals occurrences which form the accessories within this formation however, this formation is rich in microfauna contents especially foraminifera. The benthonic foraminiferal assemblage indicates that these sediments were deposited on shallow marine shelf as a pre-deltaic sequence (Cohen and MCclay, 1996). The shales lithofacies within the Akata Formation are principally uncompacted and highly pressured (Onuoha et al., 2008 and Knox and Omatsola, 1989). The depth to the abnormal pressure ranges from 2,000m along the shelf to 4,500m in the western Niger Delta (Owolabi et al., 1990) while Schlumberger, (1985) published that the pressure level in the uncompacted marine Akata shales is at

least half times the normal hydrostatic pressure. The deposition of the sedimentary offlap sequence over the Akata shale caused gravitational instability in the sub-stratum, leading to deformation, upliftment of shale diapirs, faulting and erosion during the Paleocene to Late Miocene age.

Materials and Method

A base map of the area was provided for this study (Fig. 3) while T-Z dataset was given only for well 'A' as shown in Table 2. The time – depth conversion for the key candidate surfaces (MFS & SB) was carried out using the relationship; $TVD = 200 * TWT^{1/3}$, where TVD = true vertical depth and TWT = two-way-time. This T - Z dataset therefore serves as a standard since all the wells provided for this study are located within the same macrostructure. The depth and time were plotted to establish a relationship as shown in Fig. 4 below.

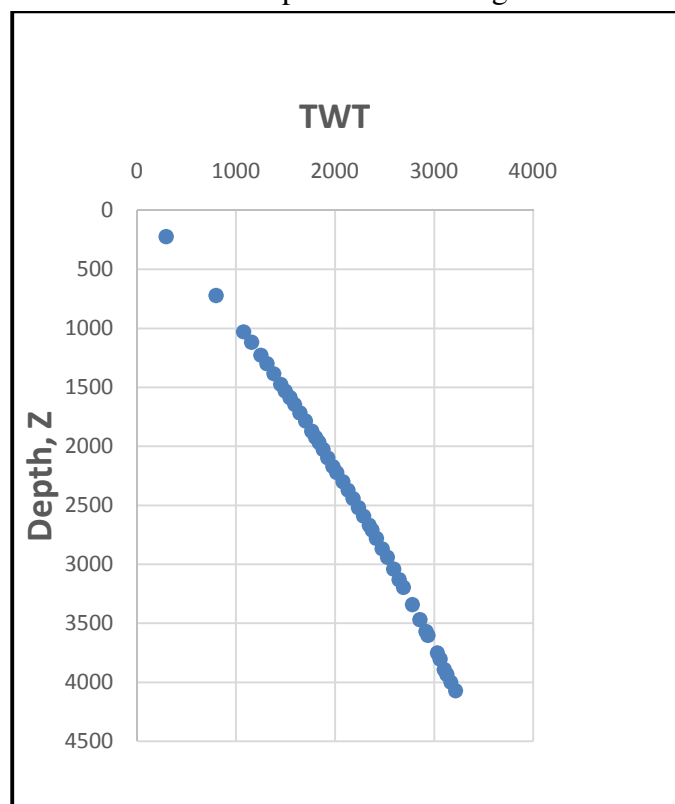
**Fig. 4. T - Z Plot for well - 'A'.**

Table 2. T - Z data for Well - 'A'

Well - A TVD	TWT					
0	0	2755	2236.7	3369	2610.8	
480.9	504.54	2778	2250.7	3393	2626.8	
1230.9	1172.2	2804	2266.7	3416	2640.8	
1355.9	1272.3	2828.9	2280.7	3438	2656.8	
1750.9	1574.5	2854	2294.7	3491	2686.8	
2107	1820.6	2877	2308.7	3511	2698.8	
2129	1832.6	2900	2324.7	3520.9	2704.8	
2151	1846.6	2921	2338.7	3534	2714.8	
2172	1862.6	2942	2352.7	3554.9	2728.8	
2194	1876.6	2964	2374.8	3575	2740.8	
2216	1888.6	2854	2294.7	3596	2752.8	
2238	1902.6	2877	2308.7	3624	2768.8	
2261	1914.6	2900	2324.7	3652	2784.8	
2283	1930.6	2921	2338.7	3690	2806.8	
2306	1944.6	2942	2352.7	3726	2830.8	
2329	1963.8	2964	2374.8	3751	2842.8	
2352	1978.6	2986	2382.8	3769	2852.8	
2375	1990.7	3008	2396.8	3879	2908.8	
2419	2018.7	3033	2410.8	3907.9	2926.8	
2444	2030.7	3059	2424.8	3965.9	2948.8	
2467	2048.7	3085	2438.8	4023.9	2970.5	
2489	2062.7	3111	2452.8	4081.9	2992.5	
2510	2076.7	3137	2468.8	4139.9	3014.8	
2531	2092.7	3160	2482.8			
2568	2118.7	3181	2496.8			
2594	2136.7	3202	2510.8			
2617	2150.7	3225	2524.8			
2637	2164.7	3252	2540.8			
2659	2178.7	3276	2554.8			
2683	2194.7	3301	2568.8			
2706	2208.7	3325	2582.8			
2730	2222.7	3348	2596.8			

N/B: TVD (m) = True Vertical Depth and TWT (ms) = Two-Way-Time

Using the above relation, all the key surfaces delineated from the biostratigraphic analyses, marked and defined in well log to correlate with the seismic section crossing through this and then to interpolate it further. The time in seconds was plotted on the horizontal axis while depth in meters was plotted on the vertical axis for all the encountered Sequence boundaries in all the five given wells ('B', 'D', 'E', 'A' and 'C') were also evaluated in this study.

Results and Discussion

Seismo-structural interpretation

Wells in this study as indicated on the base map of Fig. 3 above, belong to 'X' and 'Y' fields. These wells are situated within two fault blocks which are trending NS – NE and dipping basinward as observed from seismic section T – T' and the

correlation template (Fig. 5). They are strongly affected by fault structures which are almost same in styles within their respective placements in their sections, although they were observed from different seismic horizons in these study wells. However, all the seismic sections within 'X' Field (A - A', B - B' and C - C') are much similar in fault styles with differential mode in terms of their orientations. These faults encountered in these wells include normal growth, crestal (synthetic and antithetic) and minor counter - regional faults respectively. It has been observed that the normal faults are dipping in a north – south direction, crestal faults (including the synthetic and antithetic) are conspicuously dipping in the (north – west and north – east) landward direction while the counter regional fault (back - to - back) are dipping in a west – south direction respectively. In other hand, the normal faults are seen projecting out extensively and acts as an extensional fault into the proximal (hummocky/chaotic facies) settings in almost all the seismic sections and the wells analysed. These faults which form a network of regional and minor faults control the general architecture of the deposits in the study area. Faults designated as W and Z are situated south of wells 'C' and 'D' and north of Wells - 'A', 'E' and 'D'. The dip NE – NS is at angles estimated to be between 25° around the surface and 40° down depth. These faults inflict some displacements on the blocks where the wells were drilled. Within the correlation framework, wells - 'B', 'C' has an average of 394m fault throw (along strike) with well - 'B' on the upthrown side relative to 'C'; wells - 'A', 'E' has 345m displacement on the downthrown side relative to well - 'E' while well - 'D' is situated in the up-dip and showed a fault throw value of 413m relative to well - 'E'. This throw is equally observed on the seismic section although their resolutions are very minimal. This clearly showed that wells - 'C' and 'E' are on the downthrown side relative to wells - 'A',

‘B’ and ‘D’. On the seismic section displaying all the wells (see Fig. 5), the internal reflection configuration patterns are almost parallel to sub-parallel and sometimes wavy with low to high intensity and continuity at some points where the faults are located. These two faults are interpreted as regional in extent and their estimated offset range was observed to be from 100 to 1108m.

Measuring along the lines of correlation, dips of 30° and 40° to southeast were estimated between wells - ‘A’ and ‘E’ while dips of between 40° and 50° also to southeast were estimated between wells - ‘B’ and ‘C’. However, this apparent dip direction changes is a further indication of displacements occasioned by

the faults between the blocks as the line of the dip section also change. Sediments were generally observed to be thickening basinward (southward) and across the correlated units in the five wells.

Apparently, the study within these wells are focused on reflection ranges between 1863 – 3014 milliseconds (i.e., 1.9 – 3.0secs TWT) coincident with an inference based regional studies to be from the Agbada Formation (Ogiesoba and Hammes, 2012; Morgan, 2004; Adegbeniga et al., 2003 and Allen et al., 1991). This interval is calculated to be about 3.0km (as in Table 3).

Table 3. Conversion of depth (m) to time (millisecs.) for all the key surfaces (MFS and SB) in wells - ‘B’, ‘D’, ‘E’, ‘C’ and ‘A’ along the strike direction.

Wells		‘B’		‘D’		‘E’		‘C’		‘A’	
Age	Key Dated Surfaces (Ma)	Depth (m)	Time (ms)	Depth (m)	Time (ms)	Depth (m)	Time (ms)	Depth (m)	Time (ms)	Depth (m)	Time (ms)
Late Oligocene	SB ₆ (24.9)	-	-	2215	1888	-	-	-	-	-	-
	MFS (26.2)	-	-	2280	1930	-	-	-	-	-	-
	SB ₅ (27.3)	2180	1862	2325	1944	2280	1914	-	-	-	-
	MFS (28.1)	2558	2092	2488	2062	2810	2266	2500	2062	-	-
Middle Oligocene	SB ₄ (29.3)	2685	2194	2875	2308	3120	2452	2645	2164	2170	1862
	MFS (31.3)	2940	2352	2920	2338	3200	2510	2930	2338	2470	2048
	SB ₃ (32.4)	3240	2524	3115	2452	3280	2554	3050	2424	2600	2136
Early Oligocene	MFS (33.0)	3390	2626	3190	2496	3560	2728	3330	2410	2850	2294
	SB ₂ (33.3)	3630	2768	3300	2568	3960	2926	3520	2704	3160	2482
	MFS (34.0)	3740	2830	3496	2686	4050	2970	3700	2806	3340	2582
Late Eocene/E.	SB ₁ (35.4)	3870	2852	3710	2806	4140	3014	3980	2948	3470	2656

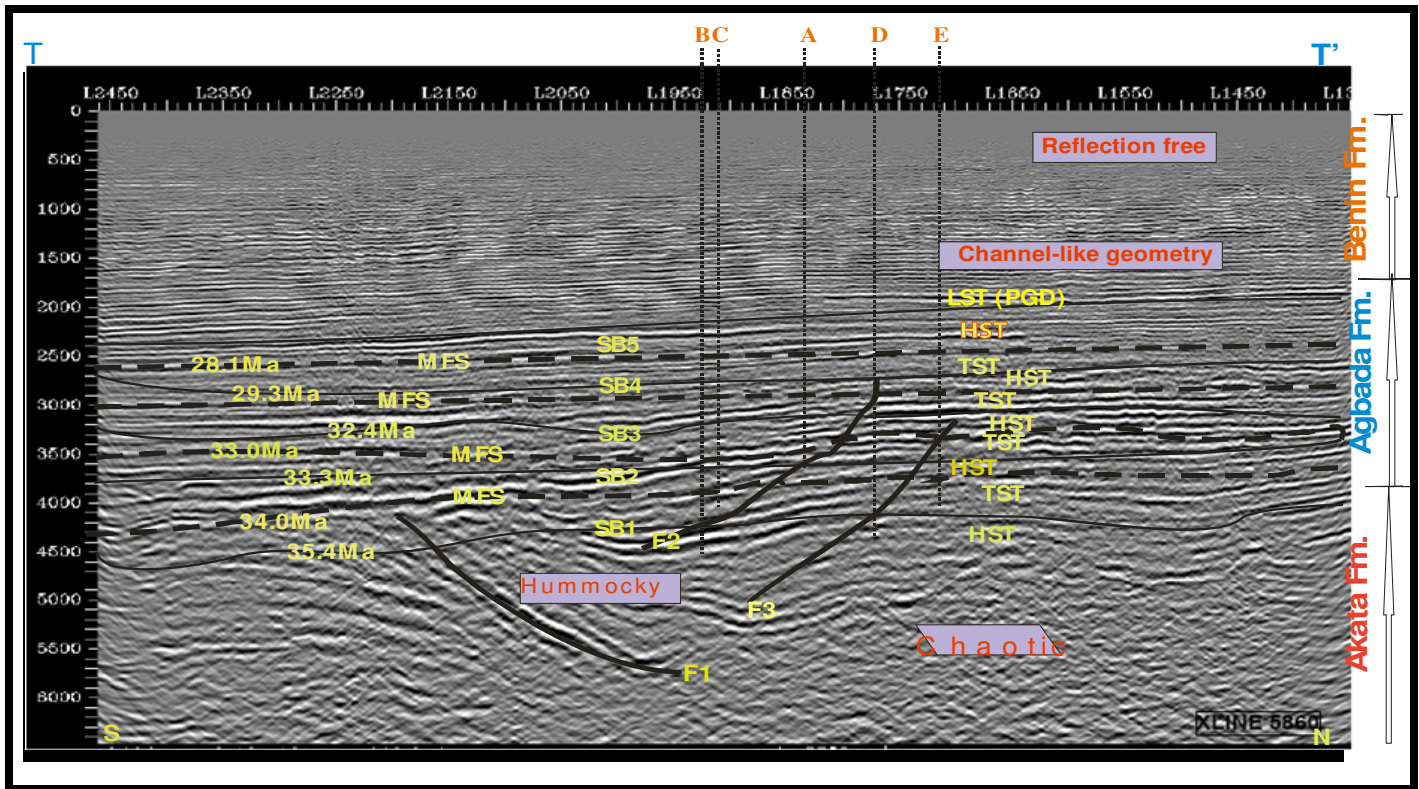


Fig. 5. Interpretation of Seismic X-line 9860 denoted as T - T'.

Seismic stratigraphic interpretation has been made in the analyses of all the seismic sections given for this study, below are the results from the respective seismic line analysed.

Interpretation of seismic line (9860) denoted as T - T':

Four seismic facies packages have been delineated in this study for seismic line X - line 9860 denoted by T - T' (Fig. 5) based on seismic attributes such as reflection configuration, uniform amplitude reflections, geometry, frequency and continuity. Within the analysed horizons of this section, the following configurations were identified. They are parallel to sub-parallel, oblique and sigmoid seismic facies and hummocky/chaotic facies. Stratigraphically the results of wells 'A', 'B', 'C', 'D' and 'E' are almost the same although structurally they tends to exhibit minor dissimilar characteristics

in terms of termination and configuration attributes as indicated in Fig. 5 and Table 4 below.

1. Facies Unit A:

This unit falls between 100 – 400m intervals, the reflection configuration identified within the section is free-like in nature. However, this may probably be characterized by single lithology and as well typically indicate the penetration of the Benin Formation within this horizon. The observed reflections within this unit had shown very low amplitude, poor continuity with no visible intensity.

2. Facies Unit B:

This facies unit occurs within 400 – 1600m intervals and displayed parallel – sub-parallel reflection configuration. The reflection continuity was generally continuous towards the base of this section with a low intensity. Uniform amplitude reflection

Table 4. Seismic Facies Characteristics for seismic X-line (9860) denoted as T - T'.

Unit/ Depth (m)	External Form/Reflection geometry	Internal Reflection Configuration	Continuity	Intensity	Depositional setting
A 100 -400	Thin sheet	Reflection free	Low	Low	Backshore - Foreshore
B 400 -1600	Sheet	Parallel - sub- parallel	Moderate	Low - Moderate	Foreshore
C 1600 -3570	Sheet-drape shape (downlap at the base)	Parallel (Sigmoidal)	High	Moderate - High	Upper- Lower shoreface
D 3570 -5500	Slump structure (base not defined)	Hummocky/ Chaotic	Low	Low	Proximal shoreface

anomalies were high basinward and moderate at the middle with uniformly narrow frequency throughout this seismic package. This facies however displayed wedge-like geometry and forms a concordant relation at the top and at the base of this package. The lithofacies analysis revealed massive sand with interbedding of shale, typical of delta front sediments.

3. Facies Unit C:

This section which shows a westward extent terminates at 3700m. It is characterized by moderate to high amplitude reflection, high continuity, variable frequency, sigmoid configuration with sheet-drape external form which is concordant. Reflection geometry shows toplap at the top and onlap at the base boundary. This seismic facies is interpreted to be associated with hemi-pelagic and sand deposits. The associated environment of deposition is channelized sand typical of prograding

shelf and slope. Three regional faults were observed towards the base of this section and are denoted by F₁, F₂ and F₃ respectively.

4. Facies Unit D:

This unit extends downward from 3700 – 5900m within the section. This interval displayed hummocky - chaotic reflection configuration patterns with highly variable frequency and sometimes sub-parallel in nature. Reflection continuity was irregular and highly discontinuous. Lithofacies analysis revealed shale deposits and mass transport complexes. External form of this facies unit and their reflection was rather variable and non-systematic while its geometry is contorted and discordant. It showed low amplitude anomalies which puts this section into a typical pro-deltaic environment. The overall time equivalent for all the wells situated on this section range between 1.9sec – 3.0sec.

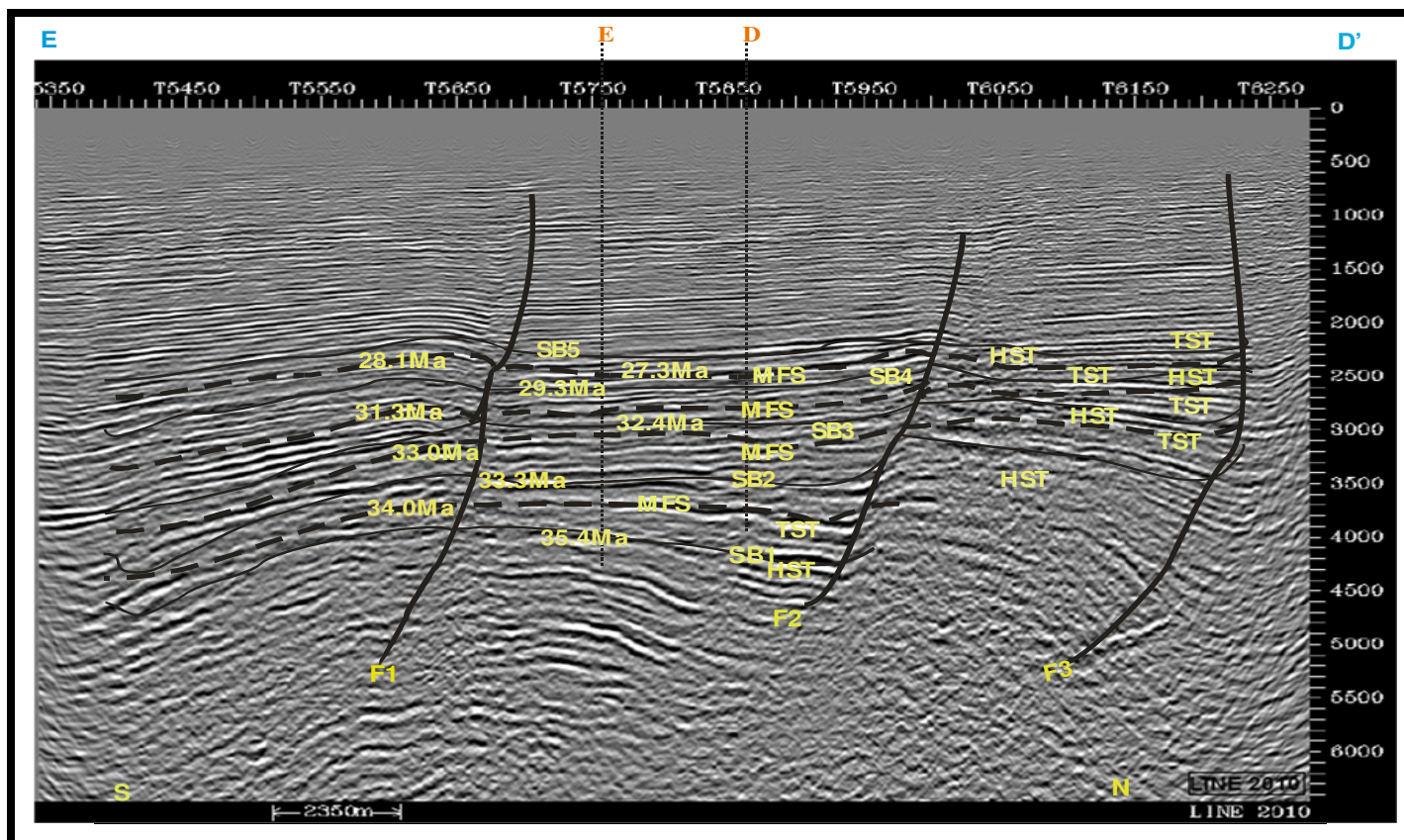


Fig. 6. Interpretation of seismic line 2010 denoted as E - D'.

Interpretation of seismic line (2010) denoted as E - D':

The stratigraphic framework has been subdivided into four seismic intervals (depositional sequences) on the basis of sequence boundary and seismic facies within this seismic section. This is presented as Fig. 6 and Table 5 below.

1. Facies Unit A:

This unit falls within 100 – 600m and exhibits a reflection of free-like configuration. It is characterized mostly by a single lithologic pattern which probably belongs to the fluvial Benin continental sands. There is a very low intensity of the reflection within this horizon as such; it has a low amplitude and poor continuity pattern as observed from the seismic section. This facies unit therefore showed a very thin sheet-like geometry form which onlap at the base of this seismic section and grossly

typified a Backshore – Foreshore depositional environment.

2. Facies Unit B:

This unit terminates at 1700m depth and it is characterized by parallel to sub-parallel reflection configuration. Low continuity of reflection was observed towards the base of this section with corresponding low amplitude reflection anomalies. However, this low amplitude is as a result of thin bedding and uniform shale and/or sand-prone lithology observed within this horizon probably indicative of wedge geometry. The frequency possessed within this horizon is low in nature from T6150 - T6250 shot points. Its boundary at the top is onlap while the base is marked by a downlapping surface. The sediments within this seismic facies were therefore deposited in the Foreshore – Upper shoreface environments.

Table 5. Seismic Facies Characteristics for seismic line (2010) denoted as E - D':

Unit/ Depth (m)	External Form /Reflection geometry	Internal reflection Configuration	Continuity	Intensity	Depositional setting
A 100 -600	Thin sheet	Reflection free	Low	Low	Backshore - Foreshore
B 600 -1700	Wedge	Parallel - subparallel	Low - Moderate	Low - Moderate	Foreshore
C 1700 -4140	Contorted fault FCD ₁ and FCD ₂ (downlap)	Divergent (Parallel)	Moderate - High	Moderate - High	Upper- Lower shoreface
D 4140 -5500	Mounded/Slump structure (base not defined)	Hummocky/ Chaotic	Low	Low	Proximal shoreface

3. Facies Unit C:

Observation made from this facies package unveiled that the facies unit terminated at 4140m depth window. The beds are continuous with high amplitude anomalies and intensity. This section showed a divergent configuration with contorted geometry (as could be seen between T5450 – T5550 shot points showing fault F₁ and between T6050 and T6150 shot point showing fault F₂). These beds appeared distorted by the presence of the faults which are denoted by FED₁, FED₂ and FED₃. This reflection package within this section is characterized by typical channel-like environments which were deposited in the Lower shoreface (delta front) setting.

4. Facies Unit D:

This unit extends further downward from 4140 – 5500m depth window. It is characterized by

hummocky/chaotic reflection configuration. The frequencies of their reflection are variable showing internal heterogeneity with high discontinuous reflection continuities. The hummocky configuration pattern was observed between T5350 and T5850 shot points while the chaotic facies shows a non-systematic array of reflection in nature between T5850 and T6250 shot points. The amplitude anomalies were low and their reflection geometry was contorted and discordant. Interpreted facies for this section include gravity mass transport and high energy turbidites current. On the other hand, the chaotic reflection pattern exhibits low amplitude which is interpreted as failed sediment masses (diapiric shale). Upon integration of information deduced from log signatures with the description given above, a proximal shoreface environment was assigned to this horizon. The time equivalent within this seismic section ranges between 2.1 – 3.0secs.

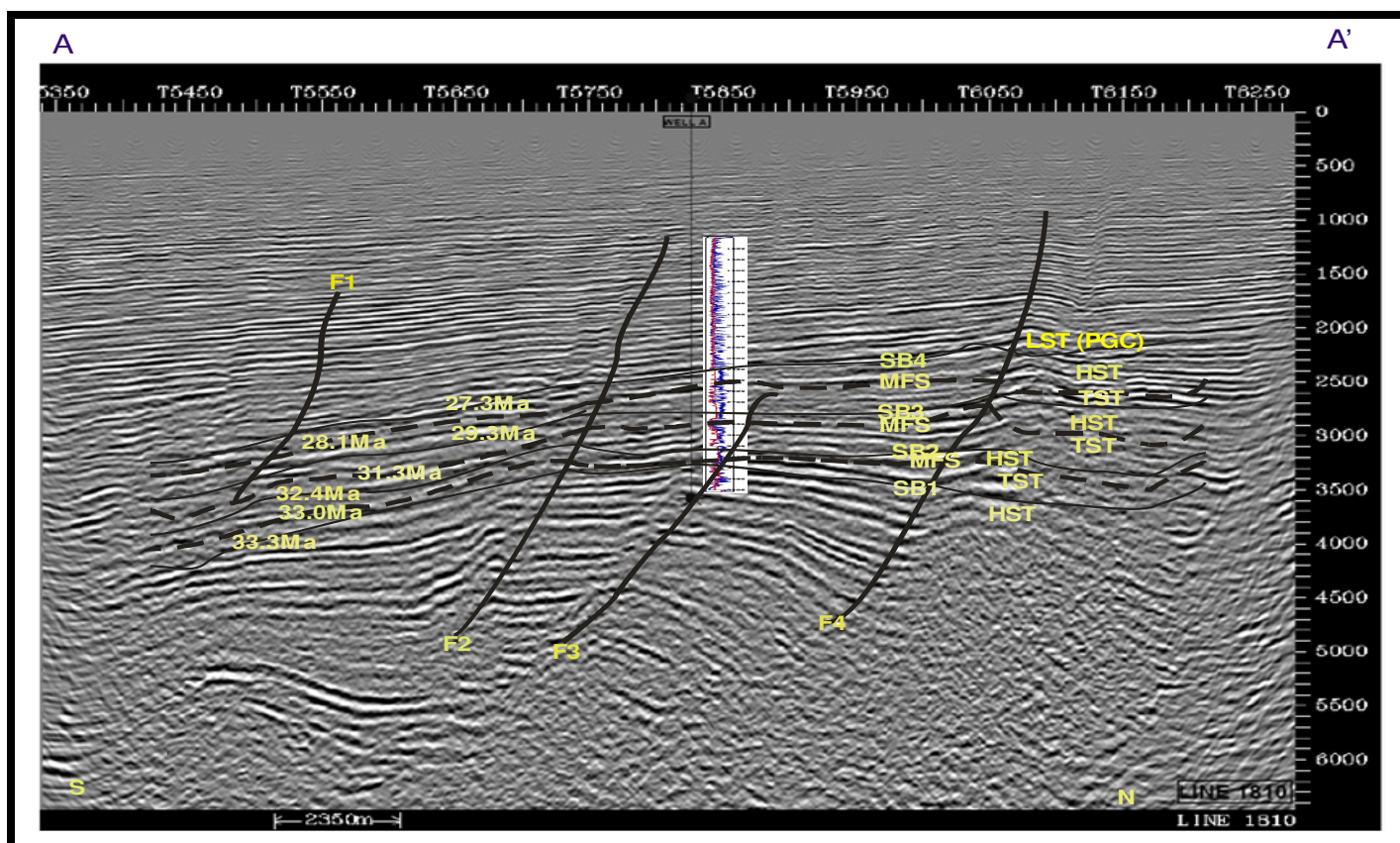


Fig. 7 Interpretation of Seismic line 1810 denoted as A – A'.

Interpretation of seismic line (1810) denoted as A – A':

This seismic section is denoted by inline 1810 which contained an assemblage of three facies unit types as shown in Fig. 7 and its characteristics are outlined in Table 6 below. However, this section has well 'A' located on it at T5828 shot point.

1. Facies Unit A:

The seismic unit within this section shows a reflection-free configuration with a truncational surface at the base boundary (400m). This is characterized by a single unit of lithology (homogenous in nature) which could probably be the Benin continental sands. The amplitude anomalies exhibited within this seismic interval is very low as such it showed poor continuity and intensity configuration pattern. This facies package has thin

sheet-like geometry; therefore, this horizon of the seismic unit has been interpreted to depict a Back-shoreface depositional environment (delta plain).

2. Facies Unit B:

This unit falls within 600- 3500m seismic interval and may probably still possess some peculiar characteristics of the above mentioned reflection package at the top. This facies unit shows a regional truncation at the top of this seismic horizon (indicates a minor regression in the Late Oligocene which is marked along the upper boundary) with parallel to sub-parallel configuration, high amplitude, moderate to high intensity and continuity. These intervals were deposited within the Lower shoreface with sheet (channel) geometry. Growth faults were observed between T5750 and T5850 windows and are represented by F₂ and F₄ with contorted structures while other important faults were seen between

Table 6. Seismic Facies Characteristics for seismic line (1810) A - A':

Unit/ Depth (m)	External Form /Reflection geometry	Internal reflection Configuration	Continuity	Intensity	Depositional setting
A 100 -400	Thin sheet - like (toplap at base)	Reflection free	Low	Low	Backshore - Fore-shoreface
B 400 -3500	Sheet/wedge (downlap at base)	Parallel - sub- parallel	Moderate - High	Moderate – High	Lower shoreface
C 3500 -5500	Slump structure (base not defined)	Hummocky/ Chaotic	Low	Low	Proximal shoreface

T5550, T6150 and T5950 shot points respectively. These faults were described as crestal (synthetic and antithetic) and counter-regional faults respectively.

3. Facies Unit C:

Unit C facies package extends from 3500 – 5500m within this section. This interval shows chaotic reflection configuration with variable characteristics. The horizon exhibits a low amplitude reflection, very low continuity and intensity. A thick sequence of high amplitude seismic facies is underlain by a low amplitude and prograded sequence/facies with contorted and slump geometry was observed within this horizon. This seismic facies unit is discordant at the base (bottomset) and indicates deposition in the proximal shoreface environment (delta front – pro-delta). The time equivalent on the seismic horizon ranges between 2.1 – 2.6secs.

Interpretation of Seismic line (1990) denoted as B - B':

This seismic section is denoted by inline 1990 and has shown four seismic facies units with their

corresponding depositional settings as shown in Fig. 8, their characteristics features are also outlined in Table 7 below. Well 'B' is located on this section at T5760 shot point.

1. Facies Unit A:

This seismic facies occurred between T5350 and T6250 shot-points and lie within 100 – 600m interval depth. It has a free reflection configuration with a relatively low frequency, amplitude, continuity and intensity. These characteristics depict sediments deposited within the Back – shoreface environments. It forms an onlap boundary at the base of the underlying horizon of the sediments.

2. Facies Unit B:

This facies unit falls within 600 – 2150m depth interval and displayed a wavy to parallel type of internal reflection configuration. This seismic facies is characterized by low to moderate amplitude and continuity with absolutely low intensity. Deposition within this horizon took place in the Foreshore – Upper shoreface environments (delta plain – delta front).

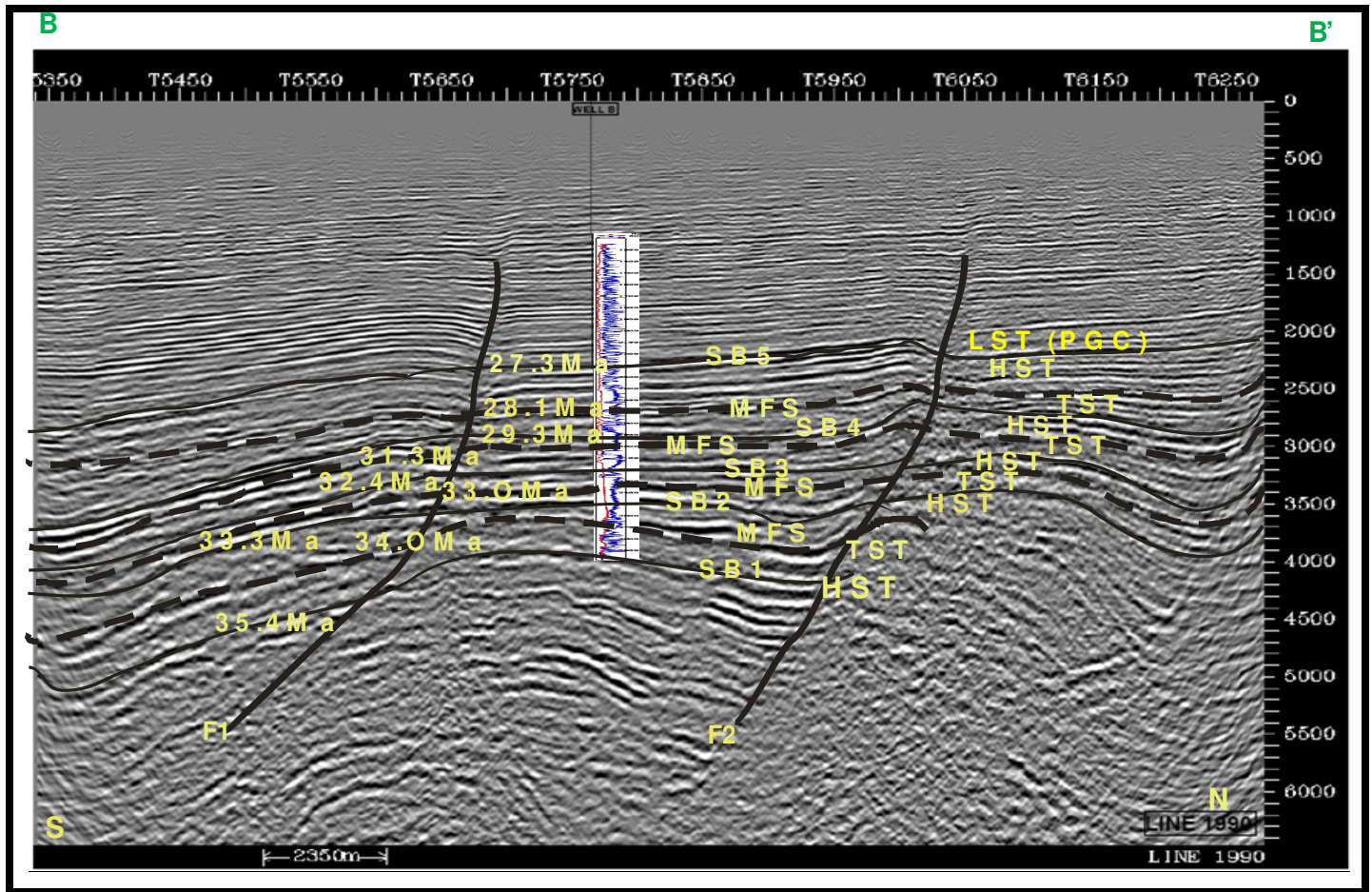


Fig. 8. Interpretation of seismic line 1990 denoted as B-B'.

Table 7. Seismic Facies Characteristics for Seismic line (1990) B - B':

Unit/ Depth (m)	External form /Reflection geometry	Internal reflection Configuration	Continuity	Intensity	Depositional setting
A 100 - 600	Thin sheet (onlap at base)	Reflection free	Low	Low	Backshore
B 600 -2150	Sheet (truncation at top and downlap at base)	Wavy - parallel	Low - Moderate	Low - Moderate	Foreshore – Upper shoreface
C 2150 -3600	Wedge shape (downlap at base)	Parallel – subparallel	High	High	Lower -Proximal shoreface
D 3600 -5500	Mounded/ Slump structure (base not defined)	Hummocky/ Chaotic	Low	Low	Proximal shoreface

3. Facies Unit C:

This seismic facies unit lies within the 2150 – 3600m interval depth. Observation from this seismic package shows that it has continuous beddings with high reflector amplitude anomalies, high continuity and intensity respectively. This section exhibits contorted geometries as these structures are indicated close to the faults (FB₁ and FB₂) projections and within this horizon is a thick wedge of shallow water deltaic deposits prograded basinward. However, this unit is downlap at the base while its depositional settings has been interpreted as being channelized deposits found within the Lower – Proximal shoreface environments (delta front – prodelta).

4. Facies Unit D:

Unit D extends from 3600 – 4500m interval depth and downward with variable high energy environment. The upper horizon of this seismic facies consists of irregular, discontinuous and sometimes sub-parallel segments which show random to hummocky internal reflection pattern and is marked by non-systematic reflection termination while the lower section shows chaotic reflection type. The fault (FB₂) observed within this seismic section has set the horizon between T6050 and T6250 shot points to be grossly uplifted (up-thrown) relative to the fault FB₁ thereby dipping the observed beds between T5350 and T5950 shot points respectively. The time equivalent on the seismic horizon ranges between 2.1 – 2.8secs.

Interpretation of seismic line (1890) denoted as C - C':

This seismic section is denoted by inline 1980 and has shown three seismic facies units with their corresponding depositional settings as shown in Fig. 9, their characteristic features are also outlined in Table 8 below. Well 'C' is located on this section at T5760 shot point.

1. Facies Unit A:

This seismic horizon contains facies unit that is not quite different from the one occurring within seismic line B - B'. This interval (100 – 600m) is characterized by free reflection pattern which are unstratified rock or sediments in nature, with homogeneous lithology.

2. Facies Unit B:

This seismic facies unit lies within 600 – 2510m interval depth and spread from T5350 – T6250 shot points. Unit B therefore displayed wavy, parallel to sub-parallel reflection configurations. Reflection was generally observed to be continuous in nature. The amplitude was high basinward (i.e. eastward). The frequency was uniformly narrow at the upper part but somehow broad at the lower part of this seismic horizon. This facies unit displayed wedged shape geometry and forms concordant relation at the top and onlap at the base boundary of the facies package. This seismic facies unit is interpreted to be associated with shale and sand deposits probably depicting channel sand which typified a prograding shelf setting within the Lower shoreface.

3. Facies Unit C:

This unit extends downward from 2510 – 3595m interval depth. The horizon is characterized by chaotic reflection configuration. Again, the frequency of the reflection within this package is highly variable with respect to its internal heterogeneity; its continuity pattern is also highly discontinuous. The amplitude anomalies are low and the reflection geometry are described as being contorted and discordant, therefore, interpretation of this facies unit is associated with high energy environments which depicts Foreshore – Upper shoreface depositional setting. The time equivalent on the seismic horizon ranges between 2.1 – 2.8secs.

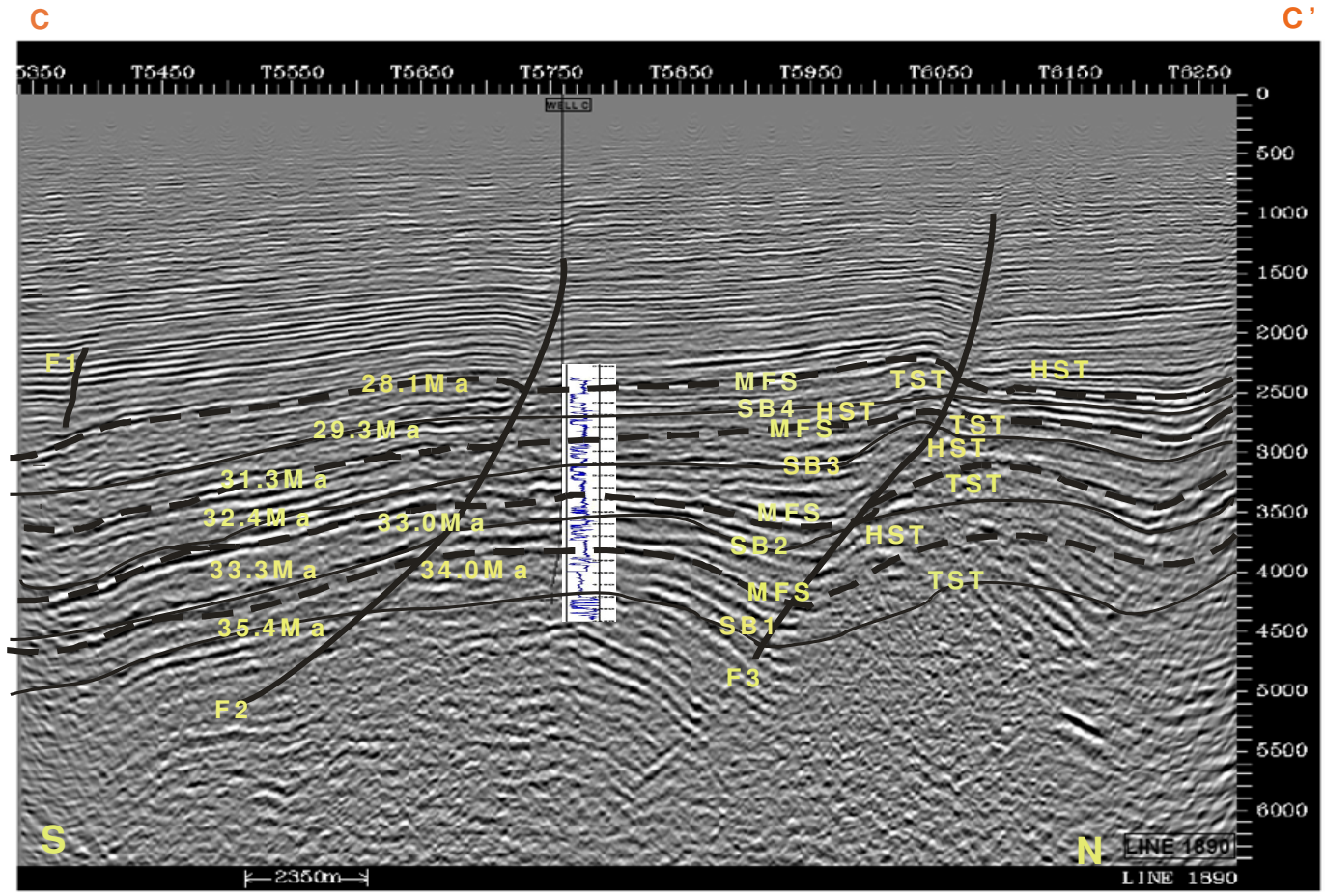


Fig. 9. Interpretation of seismic line 1890 denoted as C - C'.

Table 8. Seismic Facies Characteristics for Seismic line (1890) C - C':

Unit/ Depth (m)	External Form /Reflection geometry	Internal reflection Configuration	Continuity	Intensity	Depositional setting
A 100 -600	Thin sheet (onlap at base)	Reflection free	Low	Low	Fore-shoreface
B 600 -2510	Wedge shape (onlap at top; downlap at base)	Wavy, Parallel - sub- parallel	Moderate - High	Moderate - High	Lower - Proximal shoreface
C 2510 -3595	Slump structure (downlap at top; discordant at base)	Hummocky/ Chaotic	Low - moderate	Low	Proximal shoreface

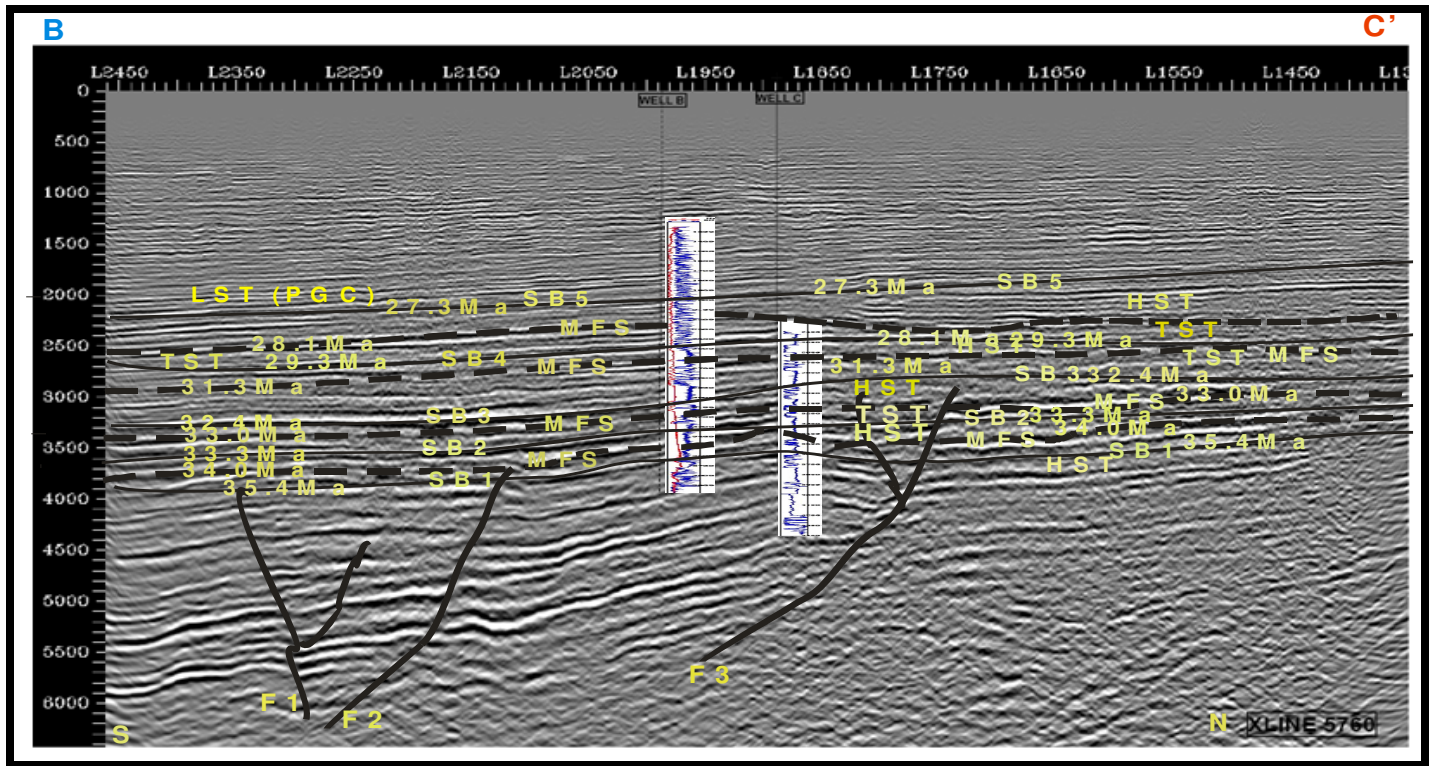


Fig. 10. Interpretation of seismic line 5760 denoted as B-C'.

Table 9. Seismic Facies Characteristics for seismic line (5760) B - C':

Unit/ Depth (m)	External /Reflection geometry	Form	Internal reflection Configuration	Continuity	Intensity	Depositional setting
A 100 -500	Thin sheet (onlap at base)		Reflection free	Low	Low	Backshore
B 500 -1600	Sheet (onlap at top)		Wavy - parallel	Low - Moderate	Moderate	Foreshore - Upper shoreface
C 160 -3500	Wedge shape (downlap at base)		Parallel-sub- parallel	High	High	Lower -Proximal shoreface
D 3500 -5900	Slump structure (base not defined)		Hummocky/ Chaotic	Low	Low	Proximal shoreface

Interpretation of seismic line (5760) denoted as B - C':

This seismic section denoted by X-line 5760 contained an assemblage of four seismic facies units as shown in Fig. 10 and its characteristics are outlined in Table 9. Moreover, this section has wells - 'B' and 'C' located on it at L1990 and L1890 lines respectively.

1. Facies Units B - C':

These seismic facies units and its characteristics encountered within this section are almost the same as those sections described for seismic lines A - A', and B - B' (see figs.7, and 8; Tables 6 and 7 above). This section shows its faults (F1, F2 and F3) orientation in the north to south direction as in Fig. 10 therefore this section B - C', is more or less correlable structurally in this respect as their close description showed the existence of the faults throw (that is, well 'B' is at the up throw side relative to well - 'C') and its displacement observed between the wells ('B' and 'C').

Conclusion

Seismic stratigraphic facies analysis of the five In-lines and one X-line was attempted. This was adopted as a predictive tool arising from assumptions concerning the development of sequence bounding unconformity surfaces which separated the sequences in time permitting large scale chronostratigraphic correlation based on stratal contact of the geometries. It was further discovered that these seismic sections possesses texture which is defined by internal stratigraphic configurations, terminations and amplitudes which are composite of seismic attributes and diverse stratigraphic properties such as lithology, thickness of the beds and its continuity. Four seismic facies packages have been delineated in this study based on seismic attributes such as reflection

configuration, uniform amplitude reflections, geometry, frequency and continuity. Within the analysed horizons of this section, the following configurations were identified. They are reflection free, parallel to sub-parallel and sometimes wavy, oblique and sigmoidal seismic facies and hummocky/chaotic facies. It was observed that on the analysed seismic lines, the Maximum Flooding Surfaces within these wells commonly appear as thick amplitude events that forms the upper bounding surfaces of sandy, bright-amplitude intervals. The respective horizons within the seismic section have been interpreted with respect to facies attributes depicting their depositional settings, thus inferring these sediments to have been deposited within Foreshore – Proximal offshore paleoenvironmental settings. Lithofacies analysis revealed shale deposits and mass transport complexes. External form of this facies unit and their reflection was rather variable and non-systematic while its geometry becomes contorted and discordant in nature. Uniform amplitude reflection anomalies were high basinward and moderate at the middle with uniformly narrow frequency throughout the seismic packages. The peaks and values of the gamma log motifs denoted all the key surfaces (MFS and SB) encountered within the seismic sections.

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